Geological Society of America Special Papers

Prologue

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Geological Society of America Special Papers 2009;454;1-5
doi: 10.1130/2009.2454(00)

The Geological Society of America
Special Paper 454
2009

Prologue

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The Southern California Continental Borderland and the associated Western Transverse Ranges constitute one of the most distinctive environments on the west coast of North America. Current thinking indicates that the physiography of the region resulted from change in plate motion during the Miocene when a remnant of the Farallon Plate was captured by the Pacific Plate off Southern California. This capture led to extensional deformation of the major upper plates within the subduction zone, rotation and translation of large crustal blocks in the region, and widespread volcanism (e.g., Nicholson et al., 1994). The continental microplate that encompasses the Western Transverse Ranges province eventually rotated at least 90° clockwise, and intense crustal extension affected parts of the region that became the Borderland. Subsequent deformation, including the development of the San Andreas Fault system, led to north-south compression in parts of the region and possible westward escape of crustal blocks. The resulting complex configuration of basins and ranges continues to be seismically active and contains small-scale examples of such physiographic features as canyons, fans, and continental slopes that bear strong similarity to much larger features found in the major oceanic basins.

As a direct consequence of the region's unique tectonic evolution, the coastline makes a right-angle turn toward the east at Point Conception, creating the northern boundary of the Santa Barbara Basin. The coastline then turns back toward the southeast and continues for hundreds of kilometers to form a large bight that extends to south of the U.S.–Mexican border. This Southern California Bight is partially isolated from the major currents of the eastern Pacific and has its own oceanic water circulation patterns, which are impacted by the unique coastline configuration, the presence of offshore islands, which partially insulate the Southern California Bight from current patterns in the adjacent Pacific Ocean, and by a range of shelves that differ greatly in width. The ocean water in the Bight tends to be warmer, and wave activity is less severe than elsewhere along the coasts of California and Oregon because the offshore islands and the high hills along much of the shoreline protect the Bight from strong winds, currents, and waves. Because of rapid uplift and easily eroded rocks in the nearby hills and mountains, intermittent rivers bring large quantities of sediment to the subaerial coastal plains and into this coastal ocean, particularly along the northern part of the Bight. Sedimentary deposits have completely filled in some basins, leading to vast, flat areas above sea level upon which human infrastructure can be constructed. The favorable weather, adequate space, gentle wave climate, and many sandy beaches beckon humans desiring the good life. This natural environment has led to the development of a giant megalopolis with a population exceeding 20 million persons.

Accordingly, because of the complex, varied geology and oceanography combined with the impact of environmental factors on the huge population, the Southern California Continental Borderland and associated Southern California Bight have drawn the attention of earth scientists for many years. Several classic publications have been written, particularly "Geology of Southern California" (Jahns, 1954), "The Sea off Southern California" (Emery, 1960), "Evaluating Earthquake Hazards in the Los Angeles Region—An Earth-Science Perspective" (Ziony, 1985), and the "Ecology of the Southern California Bight" (Dailey et al., 1993), as well as innumerable journal articles.

During the past 20 years, the U.S. Geological Survey, along with many Southern California scientific partners, has conducted extensive research on geologic and oceanographic processes in the urban ocean off Southern California. The overall goal of this research has been to explore the impact that natural processes of

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Lee, H.J., and Normark, W.R., 2009, Prologue, *in* Lee, H.J., and Normark, W.R., eds., Earth Science in the Urban Ocean: The Southern California Continental Borderland: Geological Society of America Special Paper 454, p. 1–5, doi: 10.1130/2009.2454(00). For permission to copy, contact editing@geosociety.org.

the Borderland have on the human population, and vice versa. As part of this effort we have also strived to advance our knowledge concerning fundamental natural processes themselves. This volume summarizes much of our recent work through a series of six sections, each containing several related chapters or papers.

Section 1 deals with surficial seafloor mapping and characterization. Dramatic new multibeam seafloor mapping technologies were being developed and applied during the past 20 years when we were studying the Southern California Continental Borderland. These technologies provide continuous, high-resolution bathymetric coverage of the seafloor and allow the production of images that bear striking resemblance to photographs. Such images have revolutionized our way of looking at the seafloor and have caused us to refine many of our earlier interpretations. Multibeam mosaics depicting areas off the major metropolitan areas of Southern California, particularly Los Angeles, Long Beach, Orange County (Gardner et al., 2002), and San Diego (Dartnell et al., 2006), show detailed morphologic features and serve as good base maps for process-related studies.

The papers in Section 1 (Dartnell, Chapter 1.1) deal mainly with deriving geologic and benthic-habitat information from these types of maps. The first (Dartnell and Gardner, Chapter 1.2) describes an empirical terrain analysis technique used to delineate seafloor provinces. The paper also complements earlier studies based on our mapping effort in Southern California (e.g., Gardner et al., 2003) by describing the morphology of areas recently mapped and not described previously. The second paper (Cochrane and Greene, Chapter 1.3) describes an empirical method for characterizing and estimating the extent of rocky seafloor for use in identifying benthic habitats.

Sections 2 and 3 deal with fundamental geologic and oceanographic processes that introduce, transport, and deposit sediment particles and contaminants in the Southern California Bight. Section 2 contains six papers dealing with the various steps and processes that cause eroded sediment particles to move from source locations on land, into the coastal ocean, and hence onto their final depositional sites on the shelves, slopes, and basin floors (Warrick, Chapter 2.1). Most of the papers are based, at least in part, on a series of coring cruises conducted between 1992 and 2003. During these cruises, several hundred box, piston, and vibratory cores were taken on the continental shelf, mainland slope, and inner basins of the Southern California Bight. In addition, during that same time period, a relatively dense grid of high-resolution, subbottom seismic-reflection profiles was obtained over the inner part of the Southern California Bight between the U.S. international border with Mexico and the Santa Barbara Channel. This significant new set of data has allowed us to develop a greatly expanded view of the temporal and spatial distribution of sedimentation in the Bight that leads to a better understanding of how sediment moves from source to sink.

The first paper on this subject (Warrick and Farnsworth, Chapter 2.2) shows that sediment is mainly transported into the coastal ocean by rivers, but the magnitude of this sediment input is highly variable with space and time. Most sediment is derived from the Western Transverse Ranges, and most sediment input occurs during extreme weather events that are related to El Niño–Southern Oscillation (ENSO) events. Human activities have had a large impact on sediment input to the coastal ocean. For example, the dramatic increase in sedimentation that occurred after the arrival of Europeans in the early 1800s was followed by a subsequent decline in response to the construction of dams on the major rivers. The second paper (Warrick and Farnsworth, Chapter 2.3) discusses river sediment dispersal processes, which fall into two general categories: dispersal by dilute suspension and dispersal by gravity current processes. Dilute suspensions derive either directly from hypopycnal river plumes (plumes that stay near the ocean's surface) or from sediment that was deposited on the seafloor and was then resuspended by waves and transported by currents. Gravity currents derive directly from hyperpycnal flows out of rivers (suspensions with a density greater than sea water) or from sediment that was deposited and subsequently resuspended (possibly by waves) in sufficient quantity that gravity currents carry the sediment to greater depths on the continental shelf. The specific form of sediment dispersal regime that is active depends upon which river margin type is present. The three main river margin types governing sediment dispersal in Southern California are identified.

The third paper (Alexander and Lee, Chapter 2.4) builds upon and synthesizes a large database of sediment accumulation-rate estimates that were developed from short-half-life radioisotope measurements made on core samples. This synthesis shows how accumulation rates during the past 100 years vary along the Southern California margin with distance offshore. The accumulation rates tend to decrease systematically with distance from shore, supporting the view that dilute nepheloid layers are an important factor in the transport of wave-resuspended sediment offshore. Resulting hemipelagic sedimentation becomes the dominant sediment deposition process. Accumulation rates are significantly higher off the mouth of the Santa Clara River, in the northern part of the Bight near the Western Transverse Ranges, than along the margin farther to the southeast off Los Angeles. The fourth paper (Sommerfield et al., Chapter 2.5) considers the sedimentary record for the entire postglacial period. The work shows that depositional conditions similar to the present environment were established by 8–9 ka, which followed a postglacial regression dating to 11–13 ka. Sea-level transgression around 15–10 ka relates to an increase in sediment accumulation rate on the continental slope, a consequence of coastal ravinement and downslope resedimentation. A mass balance of postglacial depositional bodies shows that the largest mass of sediment is found in the Santa Barbara coastal cell, corresponding to sediment input from the Western Transverse Ranges.

The fifth paper (Normark et al., Chapter 2.6) synthesizes a vast database of radiocarbon dates obtained from the slopes and floors of the inner basins of the Southern California Continental Borderland. This information is used in subsequent chapters both to interpret the development of fan systems in the basins and to date the most recent movement of faults. The data also show that basins that have historically received a substantial amount of sediment from rivers show a decrease in sediment supply during the middle Holocene. However, during the late Holocene, after sea level reached its present highstand condition, sediment supply rates increased in response to increased ENSO events. The last paper of this section (Normark et al., Chapter 2.7) discusses the canyon-fan systems within the basins of the Borderland and the role they play as the last step in the source-to-sink sediment transport system. The northern basins are closed bathymetrically and trap virtually all sediment, whereas the southern basins are open, and turbidity currents sometimes flow between them. The activity of individual canyons (i.e., whether turbidity currents actively pass through them) can vary depending upon sea-level state, but during the Holocene, half of the major submarine canyons in the Bight remain active conduits for turbidity-current flow. Some of the canyons are fed directly by floods from nearby river deltas; others are fed by littoral drift.

Section 3 deals with the physical oceanographic factors that move and/or transport sediment and suspended materials in the central part of the Bight (Noble, Chapter 3.1). This section is based to a large extent on a long series of measurements from current moorings, bottom tripods, and wave buoys deployed by many agencies in this part of the coastal ocean. These measurements extend back over roughly the past 20 years. The data provide an expanded picture of regional circulation patterns in the central Bight, as well as an improved appreciation of factors that lead to along-shelf and cross-shelf transport. The overall view is found to be more complex than originally thought, owing to the great variability in shelf width and coastline orientation and to the importance of internal tides and bores.

The first paper in the oceanography section (Xu and Noble, Chapter 3.2) considers the wave climate of the Bight. The dominant factor influencing waves in Southern California is the ability of Point Conception to partly shelter the entire region from the harsh ocean swell generated by remote North Pacific storms. Offshore islands also block swell from entering the Bight in some directions. Large surface waves can be generated by local storms, several of which pass through the area during each winter month. A few storms even generate large waves in the summer. The resulting wave climate varies significantly with time and place, and because the larger near-bottom wave currents are a significant factor in resuspending sediment, this is one factor that causes the spatial variability of the probability of sediment transport along this part of the continental shelf. Grain-size distributions, as well as the locations of sediment depocenters in the Bight, depend in part on these patterns.

The second paper (Noble et al., Chapter 3.3) uses recently obtained data to determine along-shelf and cross-shelf current patterns and to assess the impacts of these current patterns on sediment and pollutant transport processes. The data again show that the dramatic variability in offshore topography (shelf width and orientation) has a great influence on these current patterns. In particular, in some locations the mean and subtidal flow fields carry sediment and other suspended material off the shelf; whereas in others, the flows carry sediment onto the shelf. Also, nonlinear internal tides and bores have been found to play a greater role than previously thought, again moving sediment and suspended material from shelf to slope in some locations but from mid-shelf to beach in others. The local sediment-distribution patterns are related to these processes as well as to the wave and river input patterns discussed above.

The remaining three sections (4, 5, and 6) investigate the impacts the geologic and oceanographic environments have on the human inhabitants in Southern California and the related impacts these inhabitants have on the environment. Section 4 considers geologic hazards, specifically offshore faults, landslides, and tsunamis. These hazards, although they are in some ways hidden by the ocean, have the potential to cause great damage to coastal infrastructure and loss of human life. Section 5 considers coastal aquifers, which are sedimentary deposits that can hold drinking and industrial water for a huge coastal population, but which are vulnerable to intrusion by sea water and contamination from a variety of sources. Finally, Section 6 considers coastal pollution, where it occurs relative to observed sediment transport pathways, sedimentary depocenters, and waste-disposal facilities. The section also looks at the impact of contaminated marine sediment on living things, including benthic microfauna and macrofauna.

Most of Section 4 is devoted to tectonics and faulting (Fisher, Chapter 4.1). The first paper (Fisher et al., Chapter 4.2) discusses recent developments in understanding the tectonic evolution of the Southern California offshore. This paper complements others in Sections 2 and 3 in that it sets the environmental framework for studies of factors more closely related to human safety and health. The paper shows the tectonic evolution of the region is incorporated into three different episodes, each of which imposed a different structural imprint. Importantly, the early episodes played a major role in influencing the course of later episodes. The resulting complicated tectonic structural system makes it difficult to assess the extent, orientation, and activity of modern faults. This assessment is further complicated by the operational difficulties associated with locating surface features, observing outcrops, trenching, and estimating ground motions in the offshore regions of the Bight. The second paper (Lee et al., Chapter 4.3) discusses submarine landslides. There are two major, surficial, submarine landslide complexes in the Southern California offshore, each of which represents the latest in a series of major slope failures extending back tens of thousands of years. Activity in these two large landslide complexes represents a tsunami risk; coastal runups of as much as 10 m have been estimated for the prehistoric failures. Other, smaller, surficial failure deposits exist throughout the basin slopes of the Bight. Earthquakes most likely caused these deposits, although the specific locations of the failures were determined by other conditioning factors.

The last two chapters of the hazards section describe what is known about the locations and recent activity of offshore faults. These syntheses are based in large part on a series of seismic-reflection profiling cruises conducted over the past 10 years by the U.S. Geological Survey along a grid that was developed for the entire inshore part of the Bight from the international U.S.–Mexican border to Santa Barbara. These data are complemented by industry data that have recently become available. Fisher et al. (Chapter 4.4) describe the faults in the northern and western part of the Bight. Historical seismicity indicates that at least moderate (M5–M6) earthquakes do occur on the offshore faults; recorded earthquakes have caused considerable damage, several deaths, and likely a tsunami in the Santa Barbara area. There is also a series of active reverse and thrust faults offshore of the Transverse Ranges that could produce moderate to strong earthquakes and destructive tsunamis. Other faults to the east could produce both strike-slip and thrust earthquakes along northwest-striking faults. Because of the complex nature of the margin, transverse structures crosscut the main faults. These fault structures can segment earthquake rupture zones, altering our assessment of the likely size of potential future earthquakes. Ryan et al. (Chapter 4.5) describe the faults in the southeastern part of the Southern California Continental Borderland. Faults here tend to be northwest-trending, right-lateral, strike-slip faults. A major earthquake that occurred in the Long Beach area along one of these faults in 1933 killed many people and generated a great deal of local damage. These major fault systems are multi-stranded. Questions about continuity of slip between strands are a key unresolved element in assessing their potential for causing large future earthquakes. A complex pattern of faulting observed along the base of the continental slope may be the result of block rotation, which would account for the pattern of folding observed along the margin.

Section 5 deals with coastal aquifers, siliciclastic sedimentary bodies that are used as reservoirs for public water supplies (Edwards, Chapter 5.1). Aquifers form when relatively coarse-grained sediment is deposited in a variety of settings that include deltas and basins, which are commonly found in marine or coastal areas. Understanding the geometry, physical properties, and connectivity of these sedimentary bodies is important, if we are to determine not only how to appropriately use the fresh water they contain, but also how to avoid contamination of these aquifers by salt water and pollutants.

The first of three papers for this section (Edwards et al., Chapter 5.2) describes all of the important coastal aquifers of Southern California. There are three general types of aquifers: those in the northwest part of the Bight that strike parallel to the tectonic structure near the Transverse Ranges, those from the central part that cut across the tectonic structure at high angles, and those from the southeastern part that fill narrow fluvial valleys. Although groundwater from some of the aquifers has been overdrawn, causing subsidence and allowing seawater intrusion, most basins, particularly those with deep aquifer systems, meet state and national drinking water standards. Better understanding of the geologic character of the deposits will help planners and hydrologists maximize the usefulness of these aquifer systems and, hence, help keep the water supply safe.

The second paper (Hanson et al., Chapter 5.3) not only describes in more detail how the geologic setting impacts flow within and between aquifers but how these impacts influence the strategies that are used to manage the resource. Important geologic factors include tectonic fabric, faults and folding, sediment layering, presence of submarine canyons, and location and extent of offshore outcrops. Other factors that affect aquifer quality and usefulness include major climate cycles and human activity, which incorporates pumpage from multi-aquifer wells, streamflow infiltration, and artificial recharge. Infiltration of saline water, which is the largest coastal aquifer problem, is being dealt with in a number of ways including the use of injection barriers. The third and last paper (Edwards et al., Chapter 5.4) describes a detailed stratigraphic investigation of the Dominguez Gap, a water gap located near Long Beach, which is a critical link in the coastal aquifer systems of the Los Angeles Basin. Because the stratigraphic and structural complexity exhibited in the Dominguez Gap provides a pathway for salt water intrusion into deeper aquifers, major efforts have been exerted to limit intrusion using injection barriers. A series of high-resolution, seismic-reflection profiles, coupled with four, ~400 m deep, continuously cored wells, provide a great deal of new information that helps the community better understand the stratigraphy of sedimentary deposits in the coastal Los Angeles area. This stratigraphy has been used to develop a new sequence-stratigraphic model that can ultimately be used to improve groundwater hydrologic models of the system.

All of the processes and applications discussed in this volume are interrelated, and all have an influence on humans and other living things in Southern California. In an ideal model, regional tectonics, climate, river flow, sea level, waves and currents, contaminants, waste production, and human infrastructure work together to produce a source-to-sink sediment and contaminant transport system. When contaminants and other substances are introduced into the environment, they influence biological activity and ultimately impact humans. In two earlier special volumes, we have applied this philosophy to two specific locations. In Lee and Wiberg (2002), we conducted an initial assessment of the fate of dichloro-diphenyl-trichloroethane (DDT)–contaminated sediment on the Palos Verdes margin using a multi-pronged program that included mapping, process studies, geochemical analysis, modeling, and assessment of biological effects. In Lee and Weisberg (2003), we followed a similar program to assess the impact of contamination and anthropogenic impacts on Santa Monica Bay. The focus of the present volume is much broader and includes the entire Southern California Bight. In Section 6, the last section of the present volume, we discuss the levels of contamination found in the sediment as a result of these processes and the influence the contaminated sediment has on some of the biota (McGann, Chapter 6.1).

The first paper (Maruya and Schiff, Chapter 6.2) discusses the extent and magnitude of sediment contamination in the Bight. The work is based on a Bight-wide regional monitoring program that collected over 300 seafloor surface samples that were analyzed for contaminants and other properties. Sampling stations were located using a stratified, random design so that conclusions drawn from the data would have statistical validity. The authors found that even though the greatest mass of contamination is located below 200-m water depth, the highest concentrations are commonly found in embayments. The greatest risk for adverse biological effects is found in sediment from marinas, from Los Angeles estuaries, and from areas near large, publicly owned sewage treatment works. The patterns of contamination are consistent with patterns for long-term sediment transport.

The second paper (McGann, Chapter 6.3) considers the impacts of contaminated sediment on microfaunal communities, particularly upon foraminifera. An extensive set of species abundance data has been obtained over the past 50 years at a variety of locations ranging from Point Conception to San Diego. The results show that some species are particularly sensitive to contamination and that their abundance can be used to evaluate impact of anthropogenic contamination on microfaunal communities. Other species are tolerant of most trace-metal and organic contaminants and increase in abundance as contaminant levels rise. The third and final paper (Deets and Cash, Chapter 6.4) considers macrofaunal communities in Santa Monica Bay and assesses community relationships, natural species distributions, and response to anthropogenically derived sediment variable. Both a new method of analysis and traditional statistical methods revealed moderate to strong correlation between community relationships, total polychlorinated biphenyls (PCBs), clay minerals, and grain size.

As a final note, Bill Normark and I (HL) planned on writing this chapter together and had many conversations about it before he passed away in January 2008. The actual writing of this chapter is my own. We dedicate this volume to his memory and hope that he would have liked the way it turned out.

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Manuscript Accepted by the Society 5 November 2008

Printed in the USA